An Experimental Investigation of Thermal Conductivity of Nano Fluids Containing Al_2O_3 for Heat Extraction

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***Abstract*— Thermal conductivity of materials plays an important role in the efficiency of heat transfer in heat exchangers. Generally it is the practice of utilizing pure water for heat extraction from the processed fluids. Therefore it is essential to remove the heat from the fluid and slurry at a particular heat transfer rate in this investigation. A nano fluid, containing Al_2O_3 in pure water is utilized to remove the heat from the hot fluid with various concentration of Al_2O_3. The result revealed that the nano fluid is more efficient in heat removal and as well as show higher thermal conductivity. The increase in the addition Al_2O_3 in water increases the ability of the fluid to extract heat with better efficiency. The results show that the thermal conductivity is increase by 2 to 5 times, depending on Al_2O_3 concentration in the fluid.**

***Index Terms*— Nano-fluids, Thermal conductivity, Al_2O_3 nano particle, Heat transfer enhancement**

I. INTRODUCTION

Nano fluids, increase the heat transfer more efficiently than conventional fluids [2] and it is a mixture of nano particles in a fluid. The thermal conductivity of the nano particles influences the characteristics of nano fluids. nano fluids can be considered to be the next-generation heat transfer fluids as they offer exciting new possibilities to enhance heat transfer performance compared to pure liquids It is an established fact that the content of the nano particles highly influence the thermal conductivity and therefore, in this work, the effect of aluminum oxide in water is studied for thermal conductivity. This phenomenon helps us to understand the change in the transport properties of the nano fluid with reference to pure water.

A colloidal mixture of nano particles in base fluid, called nanofluids, extremely enhances the heat transfer characteristics of the base fluid. These nano fluids have posses an enhancement of heat transfer, improvement in thermal conductivity, increase in surface volume ratio, thermophoresis, Brownian motion, etc., [7].

A little quantity of nano particles as oxides in fluids has higher thermal conductivity than in the base fluids without nano particles. Enhancing the thermal conductivity of nano fluids depends on shape and size of the particle [8].

Advances in materials technology, enable us the opportunity to produce material particles to the level of 10-9 m in size, which are termed as nano particles. These particles differ in properties (like mechanical, electrical, etc.,) when compared to the parent materials. The size range of the nano-particle is between 0.1-1000 nm.A few common oxide nano particles, which are in use are Zirconium oxide (ZnO) ,Aluminium Oxide(Al_2O_3) and Titanium Oxide(TiO3) While some of the metal nano particles are Gold(Au),Silver(Ag) and Copper(Cu).

The heat transfer coefficient increases with increasing particle volume concentration [4]. Li and Kleinstreuer [10] studied the thermal performance of a trapezoidal micro channel with nanofluid as working fluid. They used a temperature -dependent model for thermal conductivity that accounted for the fundamental role of Brownian motion. Their results revealed that nanofluid enhances both pumping power and thermal performance, with increasing volume fraction. Argonne has already produced nano fluids and conducted proof of-concept tests [3]. In particular, it was demonstrated that oxide nano particles, such as A1203 and CuO, have excellent dispersion properties in water, oil, and ethylene glycol to form stable suspensions.

Nguyen et al.,[13]experimentally studied the heat transfer coefficient of Al_2O_3–water nano fluid in an electronic liquid cooling system under turbulent flow conditions. The results showed that nanofluid containing 47 nm particle diameter provided lower heat enhancement than that of 36 nm particle size. Kalteh et al.,[5] numerically and experimentally studied the laminar convective heat transfer of nanofluid with two different particle diameters (100 and 30 nm) in a circular tube with constant wall temperature boundary conditions and showed larger heat transfer for smaller particle diameter.

Anoop et al.,[1] studied the convective heat transfer characteristics of alumina–water nanofluid with two particle sizes of 45 and 150 nm in the developing region of tube flow with constant heat flux. Their results indicated that nano-fluids with 45 nm particles have higher heat transfer coefficient than that with 150 nm particles. Several researchers Masuda et al.,[12] Lee et al.,[9] Xuan et al.,[14] and Xuan[15] stated that with lower nano particle concentrations (1–5 Vol%), the thermal conductivity of the suspensions can increase more than 20%. In powder form, nano particles can be dispersed in aqueous or organic base liquids to form nano fluids for specific applications. Up to date, nano fluids of various qualities have been produced mainly by small volumes by two-step technique [16].

Lo et al.,[11] to prepare Cu-based nano fluids with different dielectric liquids such as de-ionized water, with 30%, 50%, 70% volume solutions of ethylene glycol. They found that the different morphologies, which are obtained, are mainly influenced and determined by the thermal conductivity of the dielectric liquids. Cu, CuO and Cu2O based nano fluids can also be prepared by this technique efficiently. An advantage of the one-step technique is that nano particle agglomeration

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is minimized, while the disadvantage is that only low vapour pressure fluids are compatible with such a process.

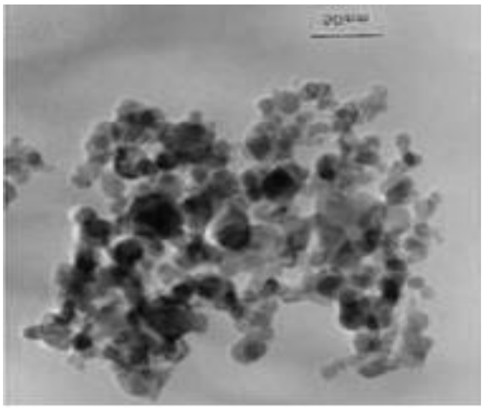

Figure 1. Nano Particle Micro Structure Aluminium Oxide(Al_2O_3)

II. PREPARATION OF AL2O3 NANO FLUID

Two-step method was used to prepare nanofluid, synthesized spherical Al_2O_3 nano particles with a diameter of 27 nm were selected as additives and deionized water is used as a base fluid. In a typical procedure, adequate surfactant (sodium-oleate) was dissolved in to the deionized water at first, then the nano particles were added gradually in to the base fluid with violent stirring. Afterwards, the suspensions were stirred by disperse mill (7200 r/min) for 40 min. Nano fluids with different volume fractions like 0.10%,0.20%,0.30% etc were obtained by intensive ultra sonication for 45 min.

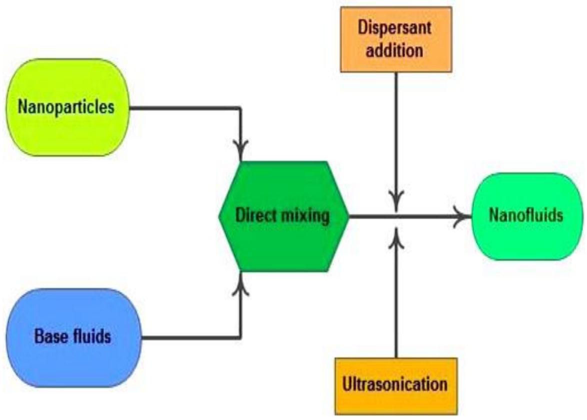

Figure 2.Flow Chart of Two Step Preparation Process and Prepared Nano Fluids

The two-step method is extensively used in the synthesis of nano fluids considering the available commercial nano powders supplied by several companies. In this method, nano particles are first produced and then dispersed in the base fluid. By ultrasonic equipment the particles are intensively dispersed to avoid agglomeration. For example, Eastman et al. [6], Lee et al. [10], and Wang et al. [11] used this method to produce Al_2O_3 nano fluids. Also, Murshed et al. [12] prepared TiO_2 suspension in water using the two-step method. Other nano particles reported in the literature are gold (Au), silver (Ag), silica and carbon nano tubes. As compared to the single-step method, the two-step technique works well for oxide nano particles, while it is less successful with metallic particles. A typical pH meter consisting of a special measuring probe (a glass electrode) connected to an electronic meter is utilized for pH measurement.

At present, the technology of the twisted-tape insert is widely used in various industries. Insertion of twisted tapes in a tube provides a simple passive technique for enhancing the convective heat transfer by introducing swirl into the bulk flow and by disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. It has been explained that such tapes induce turbulence and superimposed vortex motion (swirl flow) causing a thinner boundary layer and consequently resulting in a high heat transfer coefficient and the Nusselt number due to repeated changes in the twisted tape geometry. On consideration of the heat transfer enhancement, it can be considered through bringing the twisted-tape to insert while the pressure drop inside the tube is higher. Twisted tapes, when inserted into tubes, tend to promote turbulence as well as the intensity mixing of the hot fluid and cold fluid. Thin in turn improves the heat transfer process. Many researchers have investigated the effect of geometry of twisted-tapes on heat transfer and friction in a circular or rectangular smooth pipe in both experimental and numerical studies.

III. EXPERIMENTAL SETUP

The two step method is adopted to prepare nanofluid with synthesized spherical shaped Al_2O_3 nano particles of diameter of 27mm, where Al_2O_3 is the additive and deionised water as base fluid. For better mixing of nano particles in pure water Sodium oxalate is added to the base water. Then the mixture is stirred violently for better mixing. Immediately by utilizing disperse will (7200ypm) for about 45 minutes to evaluate the mixing. Nano fluids with 1% - 3% Al_2O_3 content were obtained by mixture ultrasonic vibration for 45minutes. The experimental setup is shown in figure.3

Figure 3. Experimental setup

The setup consists of water tank, nano fluid tank and a connection tank. To facilitate the fluid flow from water tank and nano tank to the connection tank a submersible pump is utilized. A counter flow horizontal double tube heat exchanger is controlled to study the heat exchanger process. The inner tube of the heat exchanger is made out of copper with an inner diameter of 34mm and the outer diameter is of 36mm. The outer tube is made out of GT material with inner and outer diameter of 94mm and 98mm respectively. The aluminum tape of 2mm thickness is placed inside the copper tube.

Water from the tank is heated and allowed to flow through the inner pipe and at the same time nano fluid is allowed to flow in the counter flow direction in the outer pipe. Hence the heat transfer takes place from hot fluid to cold fluid. The accessories to measure temperature, pressure are fitted in respective places to measure the flow of the fluid. Calibrated pressure gauges and thermocouples are utilized to avoid error in measurement. The inlet and the outlet temperature of the nanofluid are continuously. The reduced heat loss, the rear section is thermally isolated from its upstream and downstream sections by plastic tubes. The mass flow rates and temperature of the hot water and nanofluid are recorded. The results obtained are daily recorded in tables for discussion.

IV. EXPERIMENTAL DATA COLLECTION

The properties of Base Fluid (Water) and Al_2O_3 nano powder are tabulated in tab.1 and tab.2. These basic data has been taken from standard Heat and Mass transfer data book. (Kothandaraman)

Table 1. Base water properties

Temperature ^0C	Thermal Conductivity K_W $[Wm^{-1}K^{-1}]$	Density ϱ_w $[Kgm^{-3}]$	Specific Heat CP_w $[KJKg^{-1}K^{-1}]$	Dynamic Viscosity μ_w $[Nsm^{-2}]$ X 10^{-3}
60	0.6513	985	4.183	0.467

Table 2. properties of Al_2O_3 Nano Powder

Tempera Ture ^0C	Thermal Conductivity K_P $[WM^{-1}K^{-1}]$	Density ϱ_P $[KGM^{-3}]$	Specific Heat CP_P $[KJKG^{-1}K^{-1}]$	grain size (NM)
27	30	3890	0.880	27

V. THERMAL CONDUCTIVITY OF NANO FLUID

Thermal conductivity is defined as the quantity of heat transmitted through a unit thickness to a surface of unit area due to unit temperature gradient under steady state conditions and when the heat transfer is dependent only on the temperature gradient.

$$K_{nf} = \{[K_p+2K_w+2(K_p-K_w)\times Ø]/ [K_p+2K_w-2(K_p-K_w)\times Ø]\}K_w \quad \text{-----} \ (1)$$

Table 3. Thermal Conductivity of Nano Fluid

S.No.	Volume Fraction (ml)	Thermal Conductivity K_{nf} $[Wm^{-1}K^{-1}]$
1	0.0% (ml) Water	0.6190
2	0.1% (1 ml)	0.8039
3	0.2% (2 ml)	1.039
4	0.3% (3 ml)	1.3363
5	0.4% (4 ml)	1.722
6	0.5% (5 ml)	2.014

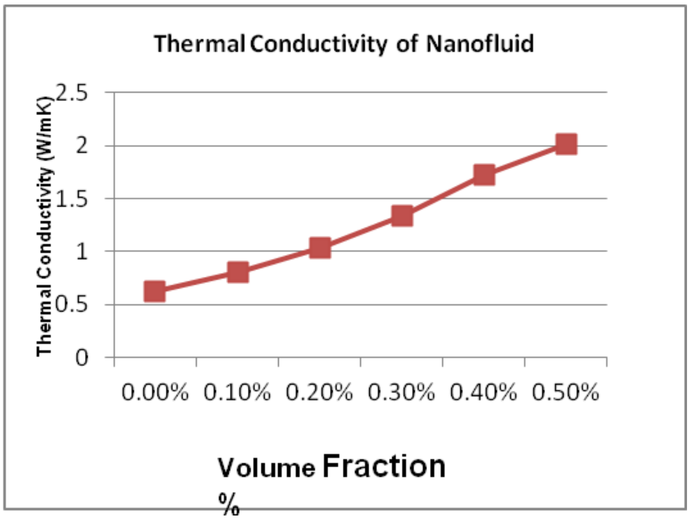

Figure 4 Thermal Conductivity (Vs) Volume Fraction of Nanofluid.

VI. SPECIFIC HEAT OF NANOFLUID

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius.

$$Cp_{nf} = Ø\ Cp_p + (1-Ø)\ Cp_w \quad \text{----} \quad (2)$$

Table 4. Specific Heat of Nanofluid.

S.No	Volume Fraction (ml)	Specific Heat (KJ $Kg^{-1}K^{-1}$)
1	0.10%	3.848
2	0.20%	3.518
3	0.30%	3.188
4	0.40%	2.858
5	0.50%	2.722

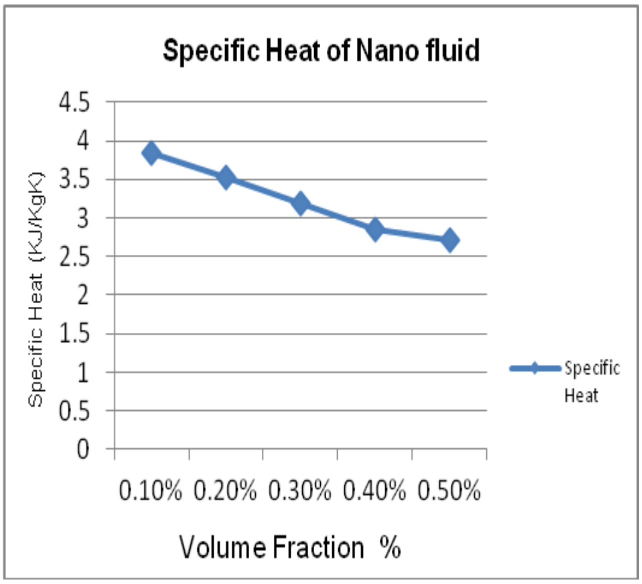

Figure 5 Specific Heat of Nanofluid (Vs) Volume Fraction

EXPERIMENTAL OBSERVATION OF HOT WATER WITH BASE FLUID (COLD WATER WITHOUT NANO PARTICLES)

Table 5. Experimental Observation of Base Fluid / Base Fluid

TIME (Min)	Base Fluid (Hot Water) Kg	Base Fluid (Cold Water) Kg	Temperature of Base Fluid (Hot) °C		Temperature of Base Fluid (Cold) °C	
			Inlet T_{hi}	Outlet T_{ho}	Inlet T_{ci}	Outlet T_{co}
2	2	8	60	53	32	35.2
4	2	8	60	50	32	35.8
6	2	8	60	48.5	32	36.1

HEAT TRANSFER RATE OF BASE FLUID (HOT)

$Q_w = m_w Cp_w(T_{hi} - T_{ho})$ ------- (3)

Determination of Heat Transfer Rate of Base Fluid (Hot)

$Q_h = 2\times4183\times(60\text{-}53)$

$Q_h = 58.562\times10^3$ J

HEAT TRANSFER RATE OF BASE FLUID (COLD)

$Q_w = m_w Cp_w(T_{co} - T_{ci})$ ----- (4)

Determination of Heat Transfer Rate of Base Fluid (Cold)

$Q_c = 8\times4178\times(35.2\text{-} 32)$

$Q_c = 106.956 \times10^3$ J

HEAT TRANSFER COEFFICIENT OF BASE FLUID/ BASE FLUID

A measure of the ability of a material to transfer heat per unit time, given one unit area of the material and a temperature gradient through the thickness of the material. It is measured in watts per meter per degree Kelvin.

$H_{b/b} = Q_{avg}/(\Delta T_m\times A)$ W/m^{2}K ----- (5)

$Q_{avg} = (Q_h + Q_c)/2$ ---- (6)

$\Delta T_m = [(T_{hi}\text{-}T_{co}) - (T_{ho}\text{-}T_{ci})]/ \ln[(T_{hi}\text{-}T_{co}) / (T_{ho}\text{-}T_{ci})]$ ---- (7)

Surface area A $= \pi\times D_i\times$length

Determination of Heat Transfer Coefficient of Base Fluid / Base Fluid

$Q_{avg} = (58.562\times10^3 + 106.956 \times10^3)/2$

$Q_{avg} = 56.406\times10^3$ J

$\Delta T_m = [(24.8)\text{-}(21)]/\ln[(24.8/21)]$

$\Delta T_m = 22.850$ °C

A $= \pi\times0.096\times0.8$

A = 0.2412 m^2

$H_{b/b} = (56.406\times10^3)/ (22.850 \times10^3 \times 0.2412)$

$H_{b/b} = 10.2312\times10^3$ J/m^2 °C

EXPERIMENTAL OBSERVATION OF BASE FLUID HOT WATER WITH COLD AL2O3 NANO FLUID

Table 6 Experimental Observation of Base Fluid with different proposition of nano fluid

Volume Fraction	TIME (Min)	Base Fluid (Hot Water) Kg	Base Fluid (Cold Water) Kg	Temperature of Base Fluid (Hot) °C		Temperature of Nano Fluid (Cold) °C	
				Inlet	Outlet	Inlet	Outlet
0.10%	2	2	8	60	50	32	35.4
	4	2	8	60	48	32	35.8
	6	2	8	60	47.5	32	36.2
0.20%	2	2	8	60	47	32	35.5
	4	2	8	60	44.5	32	36
	6	2	8	60	44	32	36.2
0.30%	2	2	8	60	46	32	36
	4	2	8	60	46.5	32	37.5
	6	2	8	60	46	32	37.8
0.40%	2	2	8	60	44	32	38
	4	2	8	60	43.5	32	38.4
	6	2	8	60	43	32	38.5
0.50%	2	2	8	60	43.8	32	40
	4	2	8	60	43.5	32	39.5
	6	2	8	60	43.5	32	39.5

Table 7 Heat Transfer Coefficient of Base Fluid with and without Al_2O_3 nanofluid

Volume Fraction	TIME (Min)	Base Fluid (Hot Water) Kg	Base Fluid (Nano Fluid) Kg	Heat Transfer Coefficient $h_{b/nf}$ (J/m^2 °C)
0.00%	2	2	8	10231.2
	4	2	8	11355.6
	6	2	8	12465.4
0.10%	2	2	8	18702.4
	4	2	8	19326.5
	6	2	8	20255.3
0.20%	2	2	8	19326.6
	4	2	8	22456.5
	6	2	8	25645.3
0.30%	2	2	8	21345.5
	4	2	8	30456.5
	6	2	8	34564.3
0.40%	2	2	8	40568.3
	4	2	8	41589.5
	6	2	8	44225.3
0.50%	2	2	8	40564.2
	4	2	8	49657.5
	6	2	8	51772.9

VII. CONCLUSION

Presented a technical route for preparing stable nano fluids composed of Al_2O_3 nano particles and the deionized water (DW) as the base fluid. Sodium oleate was used as surfactant, and it was proved to be beneficial to the dispersion of the Nano particles in the deionized water. The viscosity of the Al_2O_3 nanofluid strongly depends on the temperature and the volume fraction. Thermal conductivities of the nano fluids are higher than that of base fluid, and the enhanced values increase with the volume fraction of the nano particles. The convective heat transfer coefficient of the nano fluid has substantial enhancement when compared to that of the base fluid. These results indicate that the enhanced thermal conductivity is not the only mechanism responsible for heat transfer enhancement and other factors such as stability of Nano fluids, thermal properties, and viscosity of the Nano fluids also should be considered.

Investigation of enhancement efficiency, heat transfer characteristics of circular tube fitted with twisted tape inserts. It is observed that the swirl flow helps decreases the boundary layer thickness of the hot water flow and increases time of water in the outer tube. The secondary fluid motion is generated by the tape twist, and improves the convective heat transfer.

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